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13. ABSTRACT (Maximum 200 words)

A new cold strain index (CSI), based on rectal temperature and skin temperature was recently suggested (Am. J. Physiol. 277:R556-R564, 1999). The purpose of this study was to validate CSI for exercising volunteers exposed to cool (0.0°) and moderately cold (-12.3°C) conditions. Eight volunteers walked on a level treadmill at a speed of 1.34 m/s for 15 min followed by sitting for 70 min. CSI evaluated all the exercise periods with negative calculated values, whereas the sitting periods were correctly assessed with positive values ranging from 0-10. Despite the cold exposure in this study, increased metabolic heat production masked the cold stress causing an elevation in core temperature and consequently negative values for CSI. Cold strain evaluation by CSI should be restricted to sedentary exposures, because during exercise in a cold environment, rectal temperature is the limiting indicator for cold strain assessment.

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STRAIN EVALUATION IN COLD CLIMATES DURING EXERCISE BY THE COLD STRAIN INDEX (CSI)

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INTRODUCTION

Core temperature (T_{core}) as indicated by rectal temperature (T_{re}) has been generally accepted as a physiological measure in the assessment of cold strain and involved in the categorization for different stages of hypothermia (1, 2). However, T_{core} , either T_{re} or the more rapidly responding esophageal temperature (T_{es}) are not always reduced during cold exposure (2).

A new simple-to-use cold strain index (CSI) based on T_{core} and skin temperature (T_{sk}) was recently suggested (3). High correlation was found between CSI and other assessments of cold strain (3); namely, the insulation index (4), heat debt (5), metabolic heat production, and thermal sensation (6). Although CSI might not provide as detailed a description as other indices (e.g., heat debt calculation), it was found to be significantly easier to calculate, especially during online measurements. However, CSI was evaluated only using subjects during rest in cold air or immersion in cold water. The purpose of this study was to validate CSI for exercising subjects exposed to cold air while wearing different footwear.

MATERIALS AND METHODS

Eight young men (25 ± 5 yr) volunteered to participate in this study. The experimental risks were explained to all the volunteers before obtaining their written consent. The protocol was approved by the U.S. Army Medical Research and Materiel Command Human Subjects Scientific Review Board. All volunteers wore a modified version of the U.S. Army Extended Cold Weather Clothing System (ECWCS) and a new pair of test boots each day. Each subject completed ten experimental exposures, consisting of five different types of footwear and two cold climates at 0.0°C and -12.3°C . The five tested boots included the standard U.S. Army Intermediate Cold Wet Boot, insulated with 3M Thinsulate™ (Control), and four boots identical to the Control but containing different types of insulating materials. The test temperatures represented the upper and the lower limits determining the issuance of the control boot by the U.S. Army. Cold exposures consisted of walking on a treadmill for 15 min at a speed of $1.34 \text{ m}\cdot\text{s}^{-1}$, with no grade, and then sitting on a bench for 70 min. During these exposures, a 3-point mean weighted skin temperature (\bar{T}_{sk}) and T_{re} were monitored and continuously recorded every minute. CSI was calculated as suggested by Moran et al. (3):

$$\text{CSI} = 6.67(T_{coret} - T_{core0}) \cdot (35 - T_{core0})^{-1} + 3.33(\bar{T}_{skt} - \bar{T}_{sk0}) \cdot (20 - T_{sk0})^{-1}$$

where T_{core0} and \bar{T}_{sk0} are the initial measurements, and T_{coret} and \bar{T}_{skt} are simultaneous measurements taken at any time t ; when $T_{coret} > T_{core0}$, then $T_{coret} - T_{core0} = 0$.

Statistical analysis. Physiological responses for the different experimental exposures were analyzed with SAS version 6.12 software. A two-way repeated measures ANOVA was utilized to determine whether significant differences existed between the T_{re} , \bar{T}_{sk} and CSI while wearing different footwear. Significant differences reported herein are at $P < 0.05$, all data are reported as means \pm SE.

RESULTS

The largest relative drop during all the exposures at 0.0°C and -12.3°C was in \bar{T}_{sk} (Fig.1, left panel). The fall in \bar{T}_{sk} was monitored immediately after the start of the cold exposure during exercise and continued during the rest phase, whereas for T_{re} , the fall was marked only after termination of the 15 min exercise phase (Fig.1, middle panel). Furthermore, during the exercise phase T_{re} initially increased about 0.3°C followed by a decrease of about 0.5°C in both climates. The CSI dynamics during exercise showed a minor increase, but during the rest phase a linear increase was depicted (Fig. 1, right panel). At the end of the rest period, the CSI rated the exposures in the colder climate (-12.3°C) with values ranging from 2 to 3 units. However, no statistical differences were found in \bar{T}_{sk} , T_{re} , and CSI between the different exposures in the two cold climates ($P > 0.05$).

DISCUSSION

CSI assessment of men wearing ECWCS with different footwear during 15 min of exercise followed by 70 min of rest was done during exposure to two cold climates. While \bar{T}_{sk} decreased during all cold exposures, T_{re} increased during the exercise phase and decreased during the rest exposures.

It is generally accepted that T_{core} can describe physiological strain during cold exposures. However, T_{core} is independent of environmental temperature over a wide range. This study confirmed previous results (1,7) that as an indication of thermal strain in the cold T_{re} alone is of questionable value. During exercise, the increase in metabolic heat production caused an elevation in T_{core} in all environments. As a result, T_{core} during exercise could not contribute to the cold strain assessment by CSI as seen in this study (3). On the other hand, \bar{T}_{sk} continuously decreased during exercise and rest exposures. However, the maximal contribution of \bar{T}_{sk} to CSI is 3.33 units out of 10 units. Therefore, it is legitimate to question the utility of CSI during exercise in cold climates. It is shown from this study that CSI assessment during exercise for a short time (15 min) is valid. There are two reasons for the explanation of the low CSI values and no differences between subjects while wearing different footwear: a) the elevation of T_{core} during the exercise phase which is the dominant physiological parameter in thermoregulation; b) the combination of the metabolic rate, clothing, climate and exposure duration did not impose a severe enough cold strain on the subjects. We assumed that greater differences in CSI might have been observed if the exposure time during rest had continued beyond 70 min because of the differences which developed up to this point between the different footwear. Furthermore, the cold strain during this

study was not high as seen from the measured physiological parameters mainly because the subjects were dressed with the ECWCS which is considered to be a good personal protective system for cold weather.

CONCLUSIONS

CSI may be a useful tool, especially during online data acquisition and when metabolic rate measurements are not available for heat debt calculation. However, because of the way CSI is constructed further evaluation and studies should be done to examine the limits of its use particularly during exercise in cold exposures.

REFERENCES

1. Livingstone, S.D., Grayson, J., Frim, J., Allen, C.L. and Limmer, R.E. 1983. Effect of cold exposure on various sites of core temperature measurements. *Journal of Applied Physiology*, 54, 1025-1031.
2. Pozos, R.S., Iaizzo, P.A., Danzl, D.F. and Mills, Jr., W.T. 1996. Limits of tolerance to hypothermia. In: *Handbook of Physiology. Environmental Physiology*. (Am. Physiol. Soc., Bethesda, MD). p.557-575.
3. Moran, D.S., Castellani, J.W., O'Brien, C., Young, A.J. and Pandolf, K.B. 1999. Evaluating physiological strain during cold exposure using a new cold strain index. *American Journal of Physiology*, 277, (Regulatory Integrative Comp. Physiol. 46), R556-R564.
4. Veicsteinas, A., Ferretti, G. and Rennie, D.W. 1982. Superficial shell insulation in resting and exercising men in cold water. *Journal of Applied Physiology*, 52, 1557-1564.
5. Bittel, J.H.M. 1987. Heat debt as an index for cold adaptation in men. *Journal of Applied Physiology*, 62, 1624-1634.
6. Young, A.J., Sawka, M.N., Epstein, Y., DeChristofano, B. and Pandolf, K.B. 1987. Cooling different body surfaces during upper and lower body exercise. *Journal of Applied Physiology*, 63, 1218-1223.
7. Toner, M.M. and McArdle, W.D. 1996. In: *Handbook of Physiology. Environmental Physiology*. (Am. Physiol. Soc., Bethesda, MD) p.379-397.

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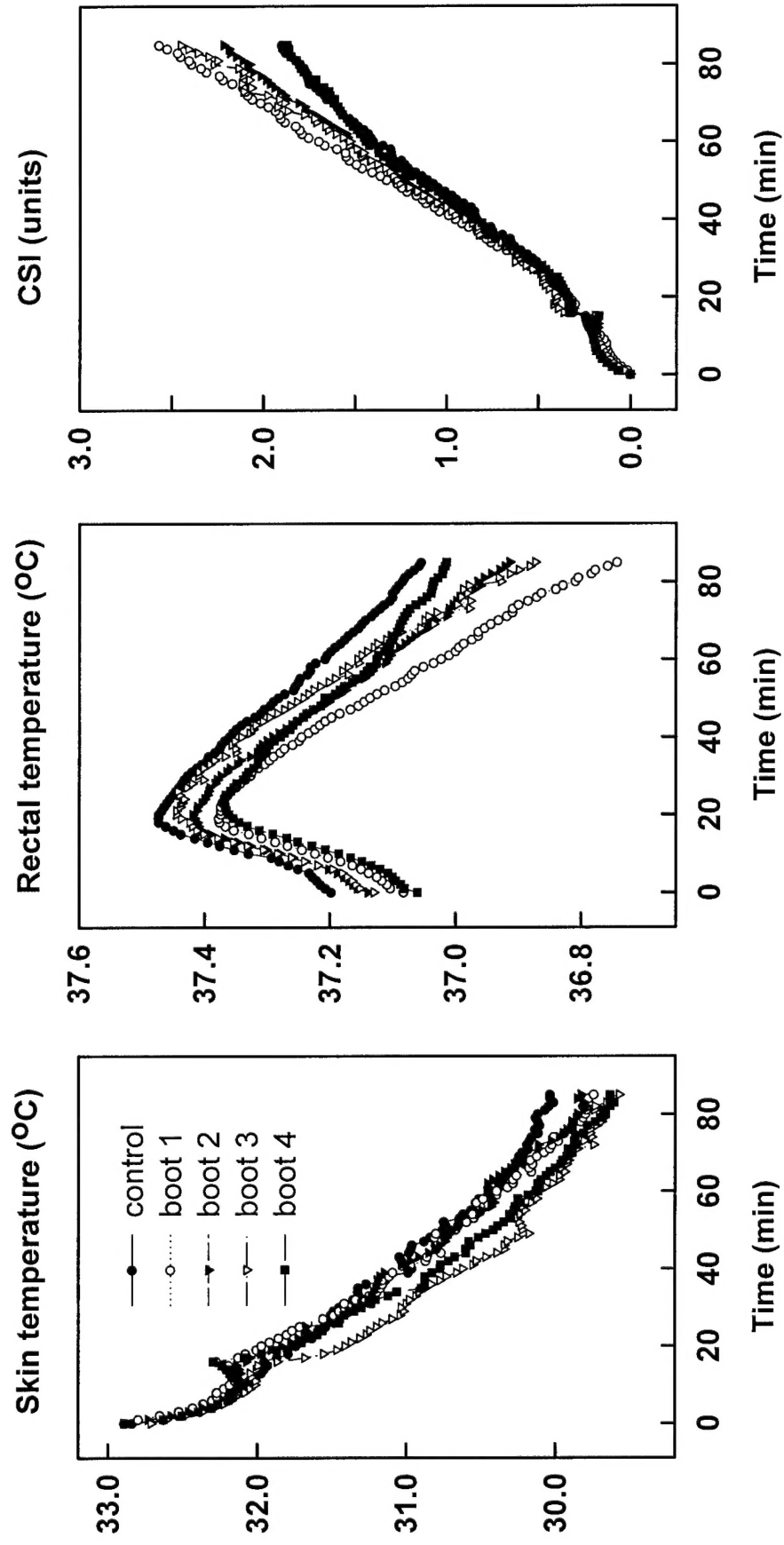


Figure 1: Mean weighted skin temperature (left), rectal temperature (middle), and CSI (right) of 8 subjects exposed to 15 min of mild exercise followed by resting for 70 min at -12.3°C with 5 different types of footwear.